Dual Use Technology for Planetary Defense Applications

John L. Remo
Quantametrics Inc.

Six technologies, CCDs, optical sensors, space propulsion, materials, hypersonic impact, and nonlinear modeling which are important support technologies relevant to planetary defense are discussed in terms of dual technology utilization. It is suggested that due to the uncertain and long term nature of the NEO threat, the technology resources allocated to developing a planetary defense should also provide economic and social benefits. Such research and development efforts dedicated to assisting critical enabling technologies that support overall economic vitality are likely to have the best opportunity for long term funding.

Introduction

The prologue to appropriate planetary defense is the development of a firm understanding of the scientific and engineering principles involving operations in a space environment and the nature of the interactions with those objects which must be defended against, ie. Earth-crossing asteroids and comets (ECACs). For example, some estimates of the chances of a 0.1km or larger ECAC colliding with the Earth are about 10 percent per century (Canavan, 1995). Assuming this number to be realistic, to some this may still appear to be a long period of time to continually support a defense system with only a small likelihood of it actually being used. This is because maintenance of such a defense system will require an extensive and detailed effort involving several areas of natural and applied science as well as the application leading edge technologies which must be supported over extraordinarily long periods of time . If the resources allocated to such an undertaking is directed purely towards planetary defense with the initial stages operating totally within and dependent upon the existing (space) research and technology development infrastructure, it may not be considered economically worthwhile. This is especially trues for those who do not accept the parameters of the NEO threat. For this reason it may be politically difficult to support a planetary defense system that does not provide some economic or social feedback. However, if this research and development is carried out from a perspective of dual use technology utilization, research and development in planetary defense can take advantage of current technology as well as provide needed stimuli for critical enabling technologies, thereby becoming cost effective while providing substantial economic benefits. Furthermore, if this planetary defense system can be integrated within ongoing space missions with a reasonable probability of economic return in the long term, the chances of support for a planetary defense system will increase accordingly.

This paper discusses aspects of some areas of science and technology relevant to planetary defense against ECACs. In particular, the relevance of charge coupled devices (CCD) and other optical detection technologies, space propulsion, materials science, hypersonic impact, and nonlinear dynamic modeling are briefly described. Issues regarding command, control, and communications are also extremely important for planetary defense issues. However, they are discussed elsewhere in the workshop proceedings (Canavan, 1995). In the technology areas outlined, it is suggested that the aforementioned technologies can significantly benefit from research being carried out both in the national/defense laboratories as well as in the industrial/commercial sectors. This cooperation between the industrial sector and the national laboratories can provide the necessary impetus to initiate research in areas critical to technological and commercial leadership. For example, the development of the SSTO as a successor to the space shuttle, which potentially represents a low cost, economically viable, gateway to LEO (low earth orbit) could provide economic benefits to private sector launch operations. Likewise, the national labs with their uniquely suited facilities will be indispensable in carrying out basic research related to radiation and hypersonic impact experiments on ECAC-type materials that would be difficult to do at industrial laboratories where the research emphasis is more on product development and quality control. Related to the above but from a slightly different perspective is the development of enabling technologies such as the CCD and its associated image processing software which are internationally market driven. Such technology provides excellent commercial opportunities, especially in medical diagnostics, public safety, and entertainment. Both ground and space based planetary defense operations using specialized CCDs will each provide valuable input into extending commercial and civil CCD applications. Finally, nonlinear analysis of celestial mechanics, which is still partially in an academic stage of development and might be considered somewhat esoteric, may generate valuable information for the development of nonlinear signal processing and chaotic control methodologies. It is therefore be suggested that by taking the appropriate and carefully measured steps focused on critical areas of technology development, research involved in long-term planetary defense can provide both near and long term economic and technological stimuli for the aerospace and electro-optics industries, as well as produce better consumer products and services.

Dual Use Technologies

The topics selected for this discussion of dual use planetary defense applications include detection, space propulsion, materials science, hypersonic impact, and non-linear analysis. Other very important topics which are not be covered in this presentation include those associated with space communications and operations, searching strategies, and overall systems analysis, for instance. These topics are discussed elsewhere in the proceedings. The five technology categories listed below are essentially described topically with little or no detail regarding the specifications of designs, observations, experiments, or analysis. It is not the intention in this brief communication to provide a technical description of these technologies. Rather, for each of the five categories the technology is first briefly described, then the planetary defense application is outlined, and finally the dual use applications are discussed.

CCD Detection

<u>Technology</u>
The first task is to seek, detect, track, and if possible optically characterize NEOs. Earth-crossing asteroid and comet (ECAC) observation, tracking and categorization will likely be achieved primarily using high performance large format charge coupled devices (CCDs) with 2560 x 1960 pixels coupled to 1-2.5 meter class telescopes. Automated operation of these telescopes will detect the NEO and

reduce (analyze) the data. Those objects which are found to be scientifically unusual and/or pose a possible threat will be further analyzed by follow up observations from specialized facilities.

Planetary Defense Application

a) Ground based observations - immediate need for funding for northern (Spaceguard) and southern hemisphere 1024 x 1024 pixel telescopes to maintain observational continuity. A proposal to build and install an array of nine 2,000 x 2,000 CCDs at the Schmidt telescope at ESO in Chile has been submitted. Also, plans exist to install a 1,500 x 1,000 CCD at the 67 m Schmidt telescope at Asiago, Italy (Hahn et al, 1995). JPL is currently fabricating a CCD camera system with a 43096 x 4096 pixel, 15 micron CCD to be installed on a 1 m telescope; the limiting visible magnitude will be about 22 (Helin, 1995).
b) Space based observations - continued development of high performance (2560 x 1960 pixel) CCDs with enhanced spectral resolution especially in the infra-red (Stokes and Kostishack, 1995). GEODSS which is designed to have a very high search rate makes it possible to envision an automated production oriented cataloging (Darrah, 1995).
c) Radar Echoes - furnish high-resolution images of near-Earth asteroids (NEAs), substantially improve the accuracy of trajectory predictions, determine rotation states, gross morphologies, and, in some cases, the (metallic) composition (Ostro, 1995a, b).

Dual Use Application

The development of large format high resolution CCD technology is a fundamental (enabling) electro-optic technology with numerous applications in the commercial marketplace including the entertainment industry, environmental monitoring, law enforcement surveillance, and in industrial production. Versions of this technology adopted for space operations are extremely valuable for evaluating Earth resources.

In particular, Matsushita Inc. is currently producing a CCD device with 10,000 half-tone levels, as opposed to conventional CCDs which produce about 500 levels of halftone. A CCD with 10,000 half-tone levels can record a composition that combines both bright and dark subjects within the same composition. This capability is especially useful in detecting passive type comets, which are highly pervious, against a background, e.g. star, field. Other applications of this technology include pocket size camcorders for professional use, navigation systems, and medical research sensing.

The software algorithms involved in the sky survey will also have several applications in industrial automated inspection and quality control, medical image scanning, and basic research in materials science. The three-dimensional computer models derived from the radar images of NEAs, in addition to challenging ones imagination with the stimulus of the unusual, are directly applicable to such critical industrial production processes as robotic vision (active and passive) and remote operations either on Earth or in space.

The coupling of an automated CCD based optical system with interpretive software is a key technology of the future, and as such its applicability to commercial, civil, social, military, medical, and industrial applications is virtually impossible to overestimate.

Optical Sensors for Environmental and Public Safety

Technology

One of the most difficult tasks in near-Earth object (NEO) mitigation is determination of their physical properties (Remo, 1994). The use of optical scanning, spectroscopy, and penetration probes can provide the means to obtain the necessary information required for hazard mitigation. Optically based technologies which can aid in these tasks include:

a) Subsurface monitoring can be carried out by laser excitation-emission spectroscopy, IR fiber optic sensors, tunable laser spectrometry, FTIR spectroscopy, and Raman spectroscopy in a cone penetrometer probe.

b) Image processing encompassing image reconstruction and restoration, image filtering, object detection and classification as well as image restoration (deconvolution) can increase the dynamic range and improve shape resolution.

c) The penetrator will also provide a good estimate, in the region of penetration, of the mechanical properties and can assist in extracting a core sample, if necessary.

Planetary Defense Application

Image processing will assist locating a faint NEO in a degraded image amid other emission sources and therefore assist in remotely determining the NEO trajectory. Image filters may also assist in estimating the NEO material properties category: ie. 0-comet type, 1-carbonaceous chondrite type, 2-stony type, and 3-iron or stony iron type. Image reconstruction will assist in estimating the size and morphology of the NEO. Knowledge of size and material composition will provide an excellent basis for evaluating the level of the NEO hazard.

Subsurface monitoring with a cone penetrator can provide an evaluation of the internal constituents of the NEO, thereby yielding information on the mechanical structure. These results can be compared with those obtained through imaging. Spectroscopy obtained from the penetrator and the surface imaging can be compared. Knowledge of the material properties and the related mechanical strength is critical for NEO hazard mitigation strategies.

Dual Use Application

a) The image processing technology which can detect faint NEOs in a noisy background is also useful, for instance, in finding small formations in tissue. For example, microcalcification clusters on the order of 50 to 100 microns can be detected amid the complex background structures in a mammogram through image processing. These structures are often indicative of breast cancer and appear as faint point-like spots. Since current mammography shows micro calcifications of 250 microns or larger, image processing is required to see the smaller spots. Additional clinical applications of image processing abound. Other areas of image processing include law enforcement and traffic safety technologies.

b) Spectroscopic probes both on the surface as well as subsurface can provide environmental monitoring above and below the ground. Also in-situ measurements of contaminated soil, water, and air can be carried out with these optical techniques. Other environmental applications include optical particle sizing for on-line monitoring of particulate emission from industrial plants, remote sensing of smoke stack and flare emissions, and remote sensing and gas analysis of aircraft exhaust.

c) Penetrator probe technology can be used in civil (construction) ground sampling, mining, hazard location and assessment, and space exploration in general.

Space Propulsion

Technology

Once a threatening ECAC has been detected, tracked, and optically characterized, the next step is to probe or otherwise engage and interact with the object at a safe distance and within a reasonably short amount of time. Repetitive missions may also be required. A long range rocket with a substantial payload will be desirable for such missions. Also, for mitigation missions a long range rocket will permit engagement with the threatening NEO at distances that allow follow up interactions with a range of kinetic and explosive devices of choice.

Planetary Defense Propulsion Applications

The need for research and development in space propulsion includes:

a) Long range propulsion - there will be a need to carry out in reasonably short periods of time an ECAC flyby, rendezvous, probe, or interception at ranges on the order of 1 AU. Such a mission calls for a (hybrid) combination of a Type I impulsive thruster which rapidly accelerates to coast speed, and a Type II propulsion system with a continuous acceleration (Sforza and Remo, 1995).

b) Single stage to orbit (SSTO) propulsion - an SSTO provides the capability for low cost LEO operations from which NEO surveillance and interception operations could be launched (Sforza et al, 1995).

c) Small, smart, and lightweight spacecraft - combined with the systems described in a and b as an option are solid- fueled (Type I version) space launch vehicles which can be quickly launched (Tedeschi and Allahdadi, 1995). This vehicle could deliver a low cost, small and lightweight instrument as a flyby, probe, (Nozette, 1995), or other device as the needs require.

Dual Use Application

The major dual use application for space propulsion systems is derived from the SSTO which will significantly reduce the cost to carry out commercial, communications, reconnaissance, and experimental operations in LEO. In addition, a low cost LEO platform will permit otherwise cost prohibitive operations to be carried out in space, thereby opening up a new horizon in space utilization and commercialization. A use for a Type II propulsion is for planetary exploration and resource exploitation.

Materials Science

Technology

Strategies for changing the trajectory of a threatening NEO by means of momentum coupling will generally consider the use of high energy radiation fluxes in the form of x-rays, γ-rays, and neutrons as well as kinetic impact. Research must be carried out on the interaction (ablation, absorption, and scattering) with the different categories (0, 1, 2, & 3) of NEO materials. The goal of this research will be the determination of the momentum coupling by radiation to the directly threatening NEO

(Hammerling and Remo, 1995). Related laser (ablation) effects can be obtained from experimental work at inertial confinement fusion (ICF) facilities which can provide additional data on X-ray absorption cross sections and related scattering effects as well as on shock wave equations of state.

Planetary Defense Application

X-ray, γ-ray, and neutron interaction cross sections with the NEO material categories 0, 1, 2, & 3 must be experimentally measured and computed over a wide variety of energies and fluxes. Initial work in computer modeling for X-ray and neutron radiation in this area as well as for kinetic and even laser coupling has been carried out by Shafer et al (1994 and 1995). The goal of this experimental and analytical research will be to model the impulse coupling to the various type of NEO materials in order to model the effects of these radiations on their velocity change.

Dual Use Application

The experimental measurements and analysis, and computer modeling on the NEO material categories will provide a very valuable date base that will have a broad range of applications which include, but are not limited to the following;

a) Development of ionizing radiation shields and scattering suppressing surfaces for medical, industrial, and military environments,
b) Nuclear radiation detection methods for environmental monitors and hazardous waste site remediation, e.g.. low level counting of neutron activated environmental samples.
c) X-ray and neutron materials processing and activation, and
d) Modeling stellar, planetary, comet, and meteorite interactions and evolution from ionizing radiation at high energy densities, e.g.. Laboratory planetary and astro-physics.

Hypersonic Impact Experiments

Technology

Experiments which involve the projectile impact on NEO materials categories 0-3 and related surrogates at 1-10 km/s must be continued to be carried out (Furnish and Remo, 1995). The goal of these experiments is to measure momentum transfer (Tedeschi et al 1995) and enhancement as well as the effects of ultra-high strain rates on the micro- and macro- structural responses.

Planetary Defense Application

The major applications of these experiments to planetary defense are to understand the response of the various NEO size, material, and morphological categories and to collect a database on the following properties:

a) kinetic impact and high energy induced shock effects,
b) momentum enhancing impacts, and
c) spallation effects.

Dual Use Applications

The numerous dual use applications resulting from hypersonic impact experiments include:

a) modeling space debris impact effects, spacecraft shielding, and EOS and constitutive models to develop improved structural materials for earthquake and blast resistant structures,

c) planetary surface penetrator design,
d) development of techniques for ECAC mining (Gertsch et al 1995), and
e) solar system formation and planetary impact dynamics.

Nonlinear Dynamic Modeling

Technology
Numerical modeling and analysis of fuzzy orbital boundary trajectories such as those involving invariant hyperbolic manifolds and "hops" between resonance states.

Planetary Defense Applications
The above nonlinear dynamical modeling may;
a) provide new routes for ECAC flybys and rendezvous and
b) interpret comet orbital trajectories.

Dual Use Application
The understanding of nonlinear analysis can provide a basis for interpreting chaotic signal processing as applied to;
a) medical, industrial, military applications,
b) provide hitherto forbidden orbital routes to asteroids, comets, or planetary bodies, and
c) lead to methods by which chaos can be controlled to enhance systems performance in general.

Conclusions

If it is perceived that there is a clear and present danger from NEOs, numerous technologies will be required to detect, track, characterize, target, and if necessary to mitigate the threat to the Earth. It is also clear that such a long term allocation of research, development, and defense resources exclusively for a NEO defense which may take thousands of years or even longer (or if at all) to pay-off by preventing a catastrophic impact on the Earth may not be politically viable over the long term. Planetary defense should be built within a technologically evolving framework that provides some benefits to society while preparing for a clear threat, should it materialize materialize. This approach will also take advantage of additional technological innovations that may be developed in the interim. Therefore, the first step in coordinating an overall planetary defense against NEOs determining which technologies are required. The next step is determining which of these technologies are currently available to the military or can be adopted from the industrial or commercial sectors. Technologies, especially those which are enabling and need to be developed in partnership with industry with the intent of providing economic and social benefits should be supported. In this way the challenge of NEO mitigation can be met in an economically, technologically, and politically realistic manner. This last comment is directed towards the realization that the plan for planetary defense against may last for centuries, if not millennia without any threat manifesting itself. A defense from such a threat runs the risk of becoming an unpopular economic burden, and therefore ultimately not be supported. If a positive economic spin-off can be maintained through dual use technology, planetary defense will rest on a better foundation and become socially more viable. By continuously developing a broad science and technology base over decades and centuries, it is not only possible, but very likely that profound new insights on the nature and mitigation of NEOs will manifest themselves. Such developments will continually change the parameters of the planetary defense strategy. We must therefore be rational and open-minded about the realistic time scales for a NEO threat to develop, evolving technological capabilities, and the need for mitigation.

Acknowledgements

I wish to thank John Darrah for suggesting to me that dual use technology be introduced into this workshop. I also wish to thank John Nuckolls for his hospitality and Bill Tedeschi for their helpful comments on this manuscript.

References

1. Canavan, G. H. , *Integration Panel Summary Report,* (1995) this proceedings.
2. Darrah, J. *The Development of Wide Field Optical Search Systems for Meteoroid and Satellite Tracking,* **Proceedings of the International Conference on Near-Earth Objects (PICNEOs),** New York, April (1995).
3. Gehrels, T., *An Overview of Discovery Programs and a Proposal to the United Nations,* ibid.
4. Gertsch, R., Lewis, J., Maryniak, G., and Remo, J., *Near-Earth Resources,* ibid.
5. Hammerling, P., and Remo, J. L., *NEO Interaction with X-Ray and Neutron Radiation,* in press, **Acta Astronautica**, (1995).
6. Helin, E., *Near-Earth Asteroid Tracking,* **PICNEOS**, New York, April, (1995).
7. Maury, A., Savalle, R., Hahn, R., Mottola, S., and Neukum, G., *EUNEASO,* ibid.
8. Nozette, S., *An Update on Clementine,* ibid.
9. Ostro, S., *Radar Observations of Near-Earth Asteroids,* ibid.
10. Remo, J. L., *Classifying and Modeling Neo Material Properties and Interactions,* **Hazards Due to Comets and Asteroids**, 551-596, T. Gehrels, ed. Tucson, (1994).
11. Shafer, B. P., Garcia, M. D., Managan, R. A., Remo, J. L., Rosenkilde, C. E., Scammon, R. J., Snell, C. M., and Stellingwerf, R. F., *Momentum Coupling to Near-Earth Objects,* **PICNEOs,** New York, April (1995).
12. Sforza, P. M., Sponable, J. M., Remo, J. L., and Schena, R. A., *Single Stage to Orbit Experimental Systems Open the Gateway to Near-Earth Orbits,* ibid.
13. Sforza, P. M., and Remo, J. L., *Space Propulsion for Critical NEO Missions,* ibid.
14. Tedeschi, W. and Allahdadi, F., *Quick Inexpensive Asteroid Rendezvous Mission,* ibid
15. Tedeschi, W., Remo, J. L., Schulze, J. F., and Young, R. P., *Experimental Hypervelocity Impact Effects on Simulated Planetesimal Materials,* **Proc. HVIS**, , October (1994).